DISCUSSION BEFORE THE WIRELESS SECTION, 6TH JANUARY, 1937, ON THE PAPERS* BY DRS. GREEN AND BUILDER (SEE PAGE 610) AND DRS. GREEN AND PULLEY (SEE PAGE 623)

Mr. W. L. McPherson: The value of the investigations described in the two papers is considerable from the point of view of ionospheric research, in which phase control of fading provides a definite improvement over the original technique. The value from the practical communication standpoint is, however, not so clear. The authors reduce fading by adjustment at both the transmitting and the receiving ends. At the transmitting end a particular form of emission is required, namely amplitude modulation, at a note frequency determined by the transmission conditions, together with suppressed carrier; while at the receiving end it is necessary to use a square-law detector, and in the majority of cases the useful part of the rectified signal is confined to the d.c. component, i.e. we are deprived of the use of note-frequency selection. Apparently to get the full benefit of the proposed system we must choose between a note frequency which will give a minimum of fading, and one which will be suitable from the normal interference standpoint in admitting the use of note selectivity by means of audio-frequency filters.

An item of rather special interest is the application of the authors' results to direction-finding and beacon work. The unreliability of the ordinary beacon and direction-finder at night has long been known, and one attempt to overcome it has been the introduction of the Adcock aerial system on both beacon transmitters and receiving direction-finders. The use of the Adcock aerial system is, however, not practicable on board ship, and it may be that the application to transmitting beacons of the principles disclosed in the paper would be of considerable value to ships fitted with direction-finders. A factor which might influence considerably this particular application is the possibility of having aural rather than galvanometer reception, as apparently would be possible

* The papers were read by Mr. J. A. RATCLIFFE, M.A., on behalf of the authors.

if double-frequency modulation were used as mentioned in connection with long-distance communication. In the section of their paper dealing with direction-finding Dr. Green and Dr. Builder discuss only single-frequency modulation, and I should like to know whether they consider that the double-frequency modulation system could be usefully applied in this case, particularly with a view to aural reception. If the system is restricted to galvanometer reception of the detector d.c. component, the prospects of its general adoption do not seem very hopeful. Alterations to the receiving equipment would be involved in so many ships that there would be a good deal of hesitation before shipowners would commit themselves to the expense entailed.

The authors state that the method they have developed for reduction of phase fading is not readily applicable to radio-telephony, yet the problem of phase fading is just as serious in radiotelephony as in radiotelegraphy. A number of attempts have already been made to solve it, the most general being the use of various diversity reception schemes with distributed aerial systems, the receiver being either fed from all the aerials simultaneously, so as to deliver an " average " signal, or perhaps automatically switched to whichever aerial happens to be the most effective at a given moment.

An alternative method now being investigated is the use of aerial arrays the directivity of which, in the vertical plane, is made so sharp as to permit reception along only one path. The interfering wave, which has traversed a different path, usually arrives at an angle sufficiently different from the " main " wave to enable effective discrimination to be made between them by virtue of the aerial directivity. Such a system requires some means of adjusting the vertical directivity, since the angle of arrival of the incoming wave is bound to vary; this can be obtained by controlling the phase-changes in the connections between the receiver and the elements of the array.

It is general experience that in radiotelephony the main trouble with phase fading occurs when the carrier component fades out. If the carrier is resupplied locally, in synchronism with the incoming carrier, a very high percentage of the fading will disappear. This is confirmed by observations made some years ago in the course of experiments relating to the relative advantages of single-side-band and full-wave systems; full-wave reception was always materially improved by the addition of local carrier, even though such accuracy of synchronization as is now contemplated was not then obtainable. Use of " local carrier " reception is therefore still another method by which phase fading can be reduced. In common with the sharply directional aerial and the diversity reception system, it is applicable to both radiotelegraphy and radiotelephony, and involves no special requirements at the transmitting end. The ultimate solution of the phase-fading problem seems more likely to lie along one of the three alternative lines of attack just mentioned than along the more restricted line dealt with in these papers.

Dr. R. L. Smith-Rose: I should like to refer to the fact that the authors are indebted for at least part of their early training and experience to the British Radio Research Board, and it is gratifying to see that they are carrying on the traditions of the work in which they were brought up in this country.

One of the main points of interest in regard to the papers is that they confirm so completely and neatly deductions which have been drawn from our present knowledge of the ionosphere. A good deal of patience and organization is necessary to get experimental results such as are described here between stations separated, as in some cases they were, by 2 000 miles or so.

One of the chief criticisms of the application of this work to a practical communications circuit is that a number of conditions have to be satisfied. For instance, it is necessary to know the distance, and also the height of the effective layer of the ionosphere, and if that height is going to vary appreciably from time to time the modulation frequency must be suitably altered in order to maintain the control; thus, to apply the authors' work to a communications circuit it appears to be essential to keep a complete record of ionospheric conditions in order to get the maximum controlling effect.

Those of us who are responsible for using direction-finders will not think a great deal of the polar diagrams which are given in Fig. 10 of the paper by Dr. Green and Dr. Builder as being representative of what can be done to-day with modern direction-finders. They are, of course, intended to show what improvements can be effected if a loop direction-finder is used. Except in the case of certain mobile receiving systems, however, such as those of ships or aircraft, it is not necessary to use a loop direction-finder. It is possible that direction-finding on ships provides a chance to apply the authors' suggestions practically, because ship direction-finders operate very largely on beacon signals intended solely for that purpose. The stations which transmit these signals are at present fitted for modulated continuous-wave emission, and if it were merely a question of selecting a particular modulating frequency it would be simple to apply the authors' idea straight away; but the real difficulty is that the distance between the receiver and the transmitter is variable, and not known at the time when the bearing is most required. The modulation frequency can only be right for one specific distance, apart from any other factors brought in by the variations in the ionosphere. Similar remarks apply in general to the analogous case of the rotating-beacon transmitter.

In thinking over this question of the possible application of the authors' work to direction-finding it has occurred to me that here is the possible answer to a discussion which went on amongst direction-finding investigators several years ago over the suggestion that the night errors of loop direction-finders were very much worse in the case of continuous-wave signals than with spark or modulated continuous-wave transmissions.* I was then of the opinion that, taking a general view from a large mass of miscellaneous data, there was no obvious difference between the accuracy of direction-finders used with continuous-wave and with modulated continuous-wave transmissions; but I can now see that it is possible that different investigators may, in certain cases, have had the conditions so adjusted, using modulated continuous-wave transmission, that their errors really were

* R. L. Smith-Rose: *Journal I.E.E.*, 1925, vol. 63, p. 923.

less than in the general case of continuous-wave transmissions.

In the application to broadcasting, as the authors have realized, there is the same difficulty of having to adjust the modulation frequency according to the distance over which it is desired to operate. Essentially in broadcasting, all the receiving sets are distributed over a wide area, and one cannot satisfy the control conditions for the receivers all at once; but, as Fig. 11 shows, one might be able to improve the general conditions, if it is not possible to meet the ideal case in every instance.

Mr. R. Naismith: Fundamentally, this problem of phase fading arises from the existence of two or more paths along which the energy may flow from the transmitter to the receiver. The difference in the lengths of these paths introduces a time factor which is used as the basis of a method, described several years ago,* to assist in the solution of this problem. It is quite obvious that if we can receive all the energy coming by the shortest path before we receive any of the energy coming by the next shortest path, we can have no phase fading. The principle of the method is to send the energy in the form of an interrupted continuous-wave signal in which the interruptions both in recurrence and in duration are related to the main paths followed by the energy in travelling from the transmitter to the receiver. This method has several potential advantages: it tackles the problem at its source and therefore increases the efficiency of transmission, it has great flexibility, and it may be used to discriminate against random noise.

Drs. A. L. Green and G. Builder and **Drs. A. L. Green and O. O. Pulley** (*in reply*): Mr. McPherson's doubts as to the possibility of making practical use of the spaced-frequency method of controlling phase-fading are irrelevant to the objects of the investigation under discussion. In the "Introduction" to the first paper† we made it clear that the object of the research, particularly that concerned with short-distance propagation, was to make a fundamental investigation of the problem of communication on spaced frequencies and to develop an experimental technique by which fading control could be achieved. No attempts were made to compare the usefulness of the spaced-frequency method with the results already achieved in other known systems, e.g. diversity reception with spaced aerials, vertical directivity steering, or local carrier insertion, and it is our opinion that the final solution of the problem of minimizing fading must lie in combining the good points of all of the available systems rather than in relying on one method alone. This attitude finds considerable support from the practice, already common in long-distance telegraphy, of using the combination of a wobbled carrier at the transmitter with space diversity in the aerials at the receiver.

In relation to diversity systems, it is of interest to notice that the spaced-frequency method of controlling fading is essentially a frequency-diversity system, and that it has the very considerable advantage of giving a maximum of improvement in the steadiness of the received signal for a minimum of diversity. This achievement is inevitably linked with the necessity to adjust the technique in accordance with the prevailing ionospheric conditions, and it is easy to see that the other type of diversity, with spaced aerials, requires a corresponding adjustment if it is to be equally efficient.

In reply to Mr. McPherson and to Dr. Smith-Rose, we were somewhat unprepared for the amount of discussion on the possibility of applying the spaced-frequency method to direction-finding. In a paper of this kind it is proper to call attention to possible applications of the fundamental method, but it is left to the specialists concerned to work out the details. At this stage it is probably sufficient to point out that, although the optimum conditions are only achieved when the technique has been precisely adjusted to the particular ionospheric conditions, yet the addition of suppressed-carrier modulation can in no case have an adverse effect on the steadiness of the signal or on the accuracy of a bearing and, on the average, there must be a definite improvement for the majority of the users of the service.

In connection with Dr. Smith-Rose's 10-year-old problem of the differences between modulated and unmodulated signals for direction-finding, it is gratifying that the fundamental investigation of spaced-frequency transmissions is capable of supplying a satisfactory answer in favour of the modulated wave.

A more exact knowledge of the mechanism of spaced-frequency propagation has also supplied the solution to a problem* encountered in some early work of the Australian Radio Research Board in which an unsuccessful attempt was made to use 100-metre waves in the Appleton–Barnett frequency-change method of measuring ionospheric heights. On no occasion were sky waves detected, and it was concluded that the properties of the ionosphere over Australia were very different from those previously measured in England. The true solution, however, is that the transmitter on H.M.A.S. "Platypus" used in these tests employed full-wave self-rectified alternating current at a frequency of 500 cycles per sec. for the anode supply of the output valves, with the result that the outgoing signals were fully modulated at a frequency of 1 000 cycles per sec. The recent work now under discussion shows that this frequency of modulation is close to the optimum for suppression of phase interference and of the Appleton–Barnett artificial fading.

In reply to Mr. Naismith, the pulse method of eliminating phase-fading deserves more consideration than it appears yet to have received. It has, however, a number of disadvantages, among which are the wide frequency spectrum required for the transmission of very short pulses and the difficulty of applying the system to telephony.

* British Patent No. 422468.

† "Control of Wireless Signal Variations."

* "Australian Radio Research Board: Second Annual Report," *Journal of the Council for Scientific and Industrial Research*, (Melbourne), 1930, vol. 3, p. 156.